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Mechanical Engineering Education for the 21st Century*

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The significant involvement of mechanical engineers in the development of new technologies, and in turn, the impact of these technologies on the world economy suggests that mechanical engineering education programs must be modernized to reflect the needs of the future. This paper will review emerging trends in engineering education in the United States for undergraduate and graduate mechanical engineering education, as well as trends in research and interactions with industry. Mechanical engineering curricula of the past and present will be discussed, and curricula for the future will be proposed. The role of accreditation criteria in the development of engineering education programs will be considered, and the involvement of industry in the development of curricula in the accreditation processes will be addressed. The industrial environment for the future will be discussed in terms of the educational expectations, balance of the work force, and in the changing role of the world economy. Mechanical engineering education programs must accommodate the changing technological and industrial environment and continue to provide a forum for intellectual growth in the next century.

INTRODUCTION

THE rate of technological advances will continue to increase over the next several decades. Many of these advances will have a significant influence on the direction of engineering education, especially mechanical engineering education. These advances will include improved manufacturing systems, new products and services, wireless communication and information systems, new and more efficient public and personal transportation systems, and full integration of computer technology into all aspects of life. Mechanical engineers will share in many of these advances in technology, and they will have a profound influence on the commerce of nations around the world.

Mechanical engineering is a dynamic discipline. Therefore, mechanical engineering education must constantly change to stimulate and accommodate technological advances and at the same time maintain a focus on the fundamentals which serve as the foundation of the discipline.

Engineering education in the United States began in 1802, with the basics of military engineering, although the first engineering degree was not granted until 1835. Since that time, the field of engineering has expanded into a wide variety of engineering education programs. In the mid-1800s, mechanical engineering programs evolved to meet the needs of the manufacturing industry. As a result, the mechanical engineering discipline served as the basic discipline for those interested in such areas as automotive, manufacturing, industrial, and aviation.

This paper will focus on the emerging trends in engineering education which influence mechanical engineering, as well as associated trends in research and industrial interaction. The curricula of the past, present, and future will be considered, and the importance of accreditation for engineering programs will be reviewed. In a similar manner, the changing industrial requirements will be examined in terms of their impact on engineering educational programs.

EMERGING TRENDS IN ENGINEERING EDUCATION

Over the past two decades, there have been demographic changes in the United States; i.e., population shifts from the northeastern part to the southern and western parts of the United States. As a consequence, there has been a geographical realignment of university enrollments throughout the country. These realignments have resulted in increased enrollments in some areas of the country, such as the southwest, while institutions in other areas of the country, particularly in the northeast, have experienced decreases. Simultaneously, the progressive role of technology in the United States has resulted in changes in education selection by students. This is not only occurring in university enrollments, but also in the selection of specific engineering disciplines. It is expected that these trends in enrollments in the southwestern part of the country will change significantly over the next decade into the 21st century.

While public institutions of higher education have benefited from significant federal and state government support in the past, the changing world economy, the struggling US economy, and

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the overly stressed state economies have spurred decreases in financial support for many higher education programs. These decreases in financial support have led to the consolidation or elimination of some degree programs in universities throughout the United States. In some areas, institutions have joined together to offer instructional programs, taking advantage of the facilities which might be shared between the institutions.

In terms of the evolving trends in undergraduate engineering education, there has been an increased emphasis on educational breadth in the past decade [1]. Institutional core curricula have become more important, and the number of university core courses has increased, placing pressure on engineering education programs to reduce the number of engineering courses in the curriculum. At the same time, there has been more flexibility in accreditation criteria, facilitating some of the broad educational requirements which are imposed on engineering education by universities.

With significant catastrophes such as the Space Shuttle Challenger explosion, the Exxon Valdez oil spill, the Hyatt Regency Hotel disaster, and others which have taken place in recent years, an increased emphasis on engineering ethics and professionalism has evolved. At the same time, more emphasis has been placed on environmental concerns and the recycling of used products. Many of these concerns have been reflected in changes in course content and course electives offered in institutions throughout the country, especially in engineering.

Relative to graduate engineering education in public institutions, there has been increased pressure from state higher education boards to reduce graduate student residence requirements for advanced degrees. The increase of costs for advanced education and the concern of state governments about the costs for advanced education have resulted in more guidelines directed toward state support for graduate study. Simultaneously, there has been greater flexibility in graduate course work, with more emphasis on interdisciplinary or multi-disciplinary study, and practice-oriented education has become more important. Many institutions also have established professional degrees which involve industrial internships or projects. Further, many graduate courses are offered through televised or videotaped programs. Overall, there is more flexibility and opportunity for graduate study today than in the past.

Financial support for graduate study has been increasingly difficult to obtain for many reasons, including the down-turn in the economy, the reduction in research funding, and the limited institutional support for graduate students. At the same time, costs for advanced education have continued to escalate, posing a dilemma for many institutions. Financial support for graduate programs has become an important issue in strategic planning for engineering education.

Basic and applied research are an integral part of most graduate engineering educational programs. In the past, there was an emphasis on single-investigator research programs, and each faculty member pursued his or her own research interest, usually on an independent basis. Recently, there has been a significant increase in joint research among faculty in the same department, among faculty within the same college of engineering, and even joint research among faculty of different institutions. This change in focus has resulted from the substantial decrease in single-investigator research funding through the federal government and other government agencies in the United States with greater emphasis on university/industry/government partnerships in research. There has also been a concomitant decrease in institutional support for research due to the state-imposed budgetary restrictions on many institutions.

While basic research funding has decreased, the development of patentable products from faculty research has become more important. Many institutions have established technology transfer offices or technology licensing offices to assist the faculty in defining, patenting, and marketing products. Further, the assignment of intellectual property rights has become a major issue. Faculty incentives to move research results to commercial production have also become issues. This new focus is viewed as a potential source of much needed financial support for continuation of the basic and applied research programs, as well as the pursuit of new research programs.

It is interesting to note that there has also been a greater interest in international collaboration between institutions, working on projects related to the improvement of technology. Theoretical work may be done in one country while experimental work for validation of the theory may be conducted in another country. International research projects also may involve individuals from several different countries.

The changing US economy has had a major impact on many industries, resulting in downsizing, outsourcing, mergers, and consolidation of products and services. Many industries have reduced or eliminated their research and development staff in order to become more efficient and profitable. These reductions in research and development staff have led to an increased focus on university/industry consortia in which representatives of several industries meet together with the faculty of one or more institutions to discuss research areas of mutual concern. It is through such endeavors, with financial support from member industries, that new ideas and concepts are developed. With such consortia, however, there also is increased concern about who owns the intellectual property rights for concepts and ideas that have been developed. Many industries now look to universities to assist them with technology transfer and to assist with programs for safety, recycling, and the environment. In the United States, there is increasing evidence that industries and universities are working together to improve technology and technology transfer.

ENGINEERING ENROLLMENT

In the United States, interest in engineering education has varied greatly over the past 25 years, as shown in Fig. 1. Perhaps the largest engineering enrollment occurred in 1982–1983, when there were more than 400,000 students enrolled in engineering throughout the United States. Since that time, there has been a steady decrease in the number of students interested in engineering, resulting in part from the changing economy, the down-sizing of industries, and the change in the military/industrial structure. Figure 1 also shows the trends in enrollment for mechanical engineering undergraduate students, which is very similar to the enrollment trends for all engineering undergraduates. In 1983, there were 71,500 students enrolled in undergraduate mechanical engineering programs in the United States, with a decrease to 61,000 in 1995.

Enrollment in master of science/master of engineering (MS/ME) graduate engineering programs is shown in Fig. 2, with the largest enrollment occurring in 1992. The total number of mechanical engineering master of science/master of engineering graduate students is also shown in Fig. 2 for comparison. In 1992, there were over 7,350 MS/ME graduate students enrolled in mechanical engineering. It is interesting to note how similar the trends are between all MS/ME engineering graduate students and mechanical engineering MS/ME graduate students.

The total engineering doctoral student enrollment is shown in Fig. 3, with the mechanical engineering doctoral enrollment indicated for comparison. The largest number of doctoral level engineering students were enrolled in 1993, with approximately 33,000 students throughout the United States. The largest number of doctoral mechanical engineering graduate students also occurred in 1993, with slightly more than 5,200 students enrolled. These increasing enrollments at the doctoral level have raised many questions with regard to potential job opportunities and the role doctoral students might play in the engineering profession in the future.

It is intriguing to consider an analysis of these data by comparing the total number of engineering graduate students enrolled to the number undergraduate engineering students enrolled, as shown in Fig. 4. The ratio of graduate to undergraduate students was approximately 23% in 1993. For mechanical engineering, the percentage of graduate to undergraduate students was 19% in 1993. While undergraduate enrollments have declined since 1982–1983, the number of graduate students has increased over that same period of time.

Another interesting comparison is the number of

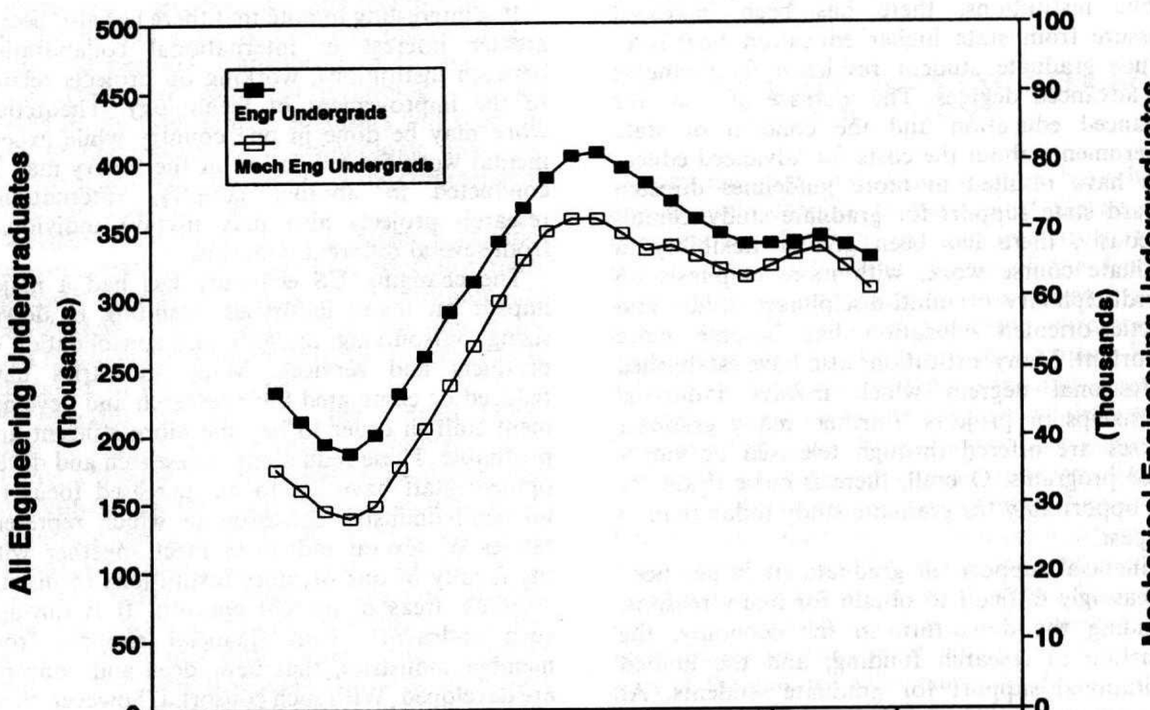

Fig. 1. A comparison of the enrollment of all engineering undergraduates with mechanical engineering undergraduates for the past twenty-five years.

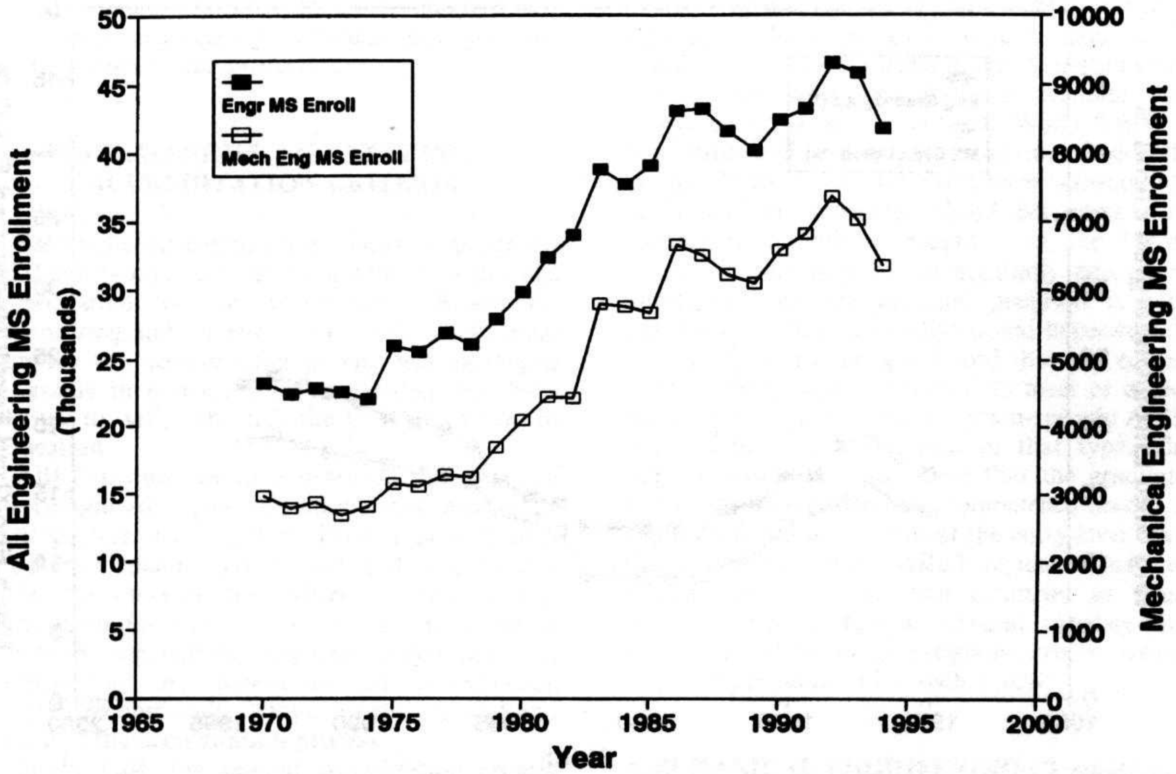

Fig. 2. A comparison of the enrollment of all masters level engineering students with mechanical engineering MS/ME level students for the past twenty-five years.

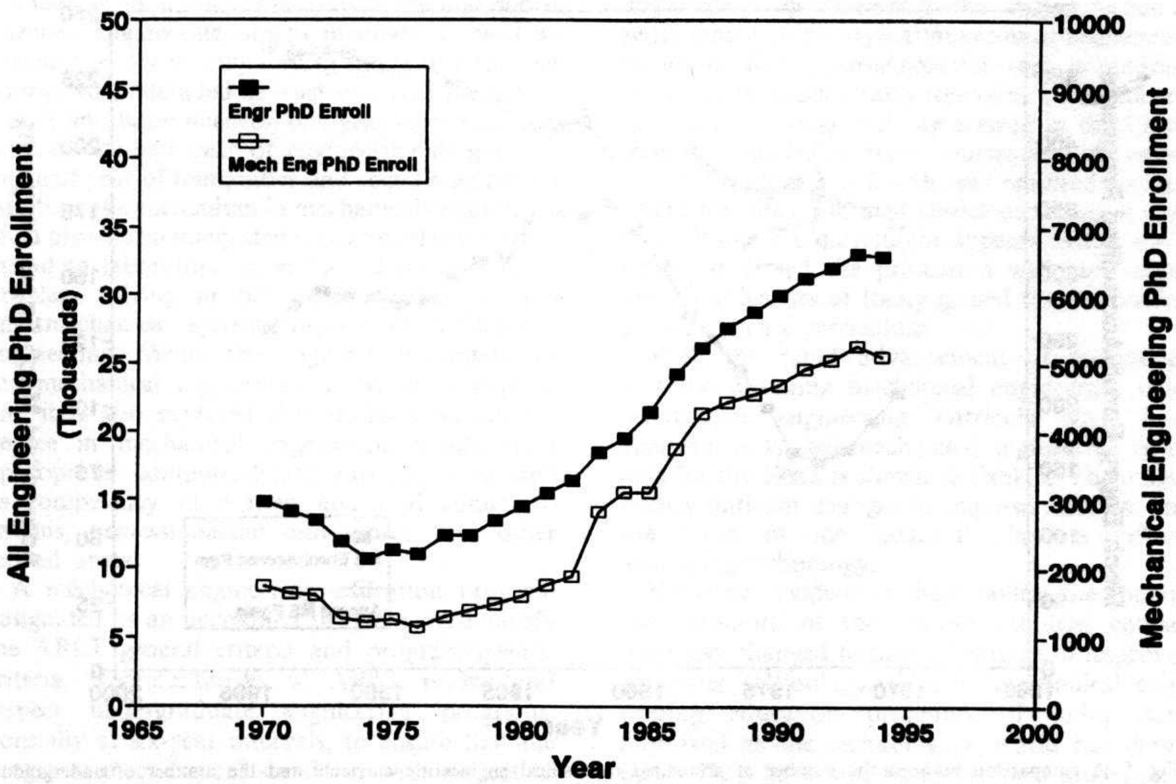

Fig. 3. A comparison of the enrollment of all Ph.D. level engineering students with mechanical engineering Ph.D. level students for the past twenty-five years.

mechanical engineering undergraduates enrolled per accredited mechanical engineering program. Figure 5 indicates that the number of accredited mechanical engineering programs in the United States has increased from 169 programs in 1970 to 236 programs in 1994. The largest number of students per accredited mechanical engineering program occurred in 1983, with approximately 350

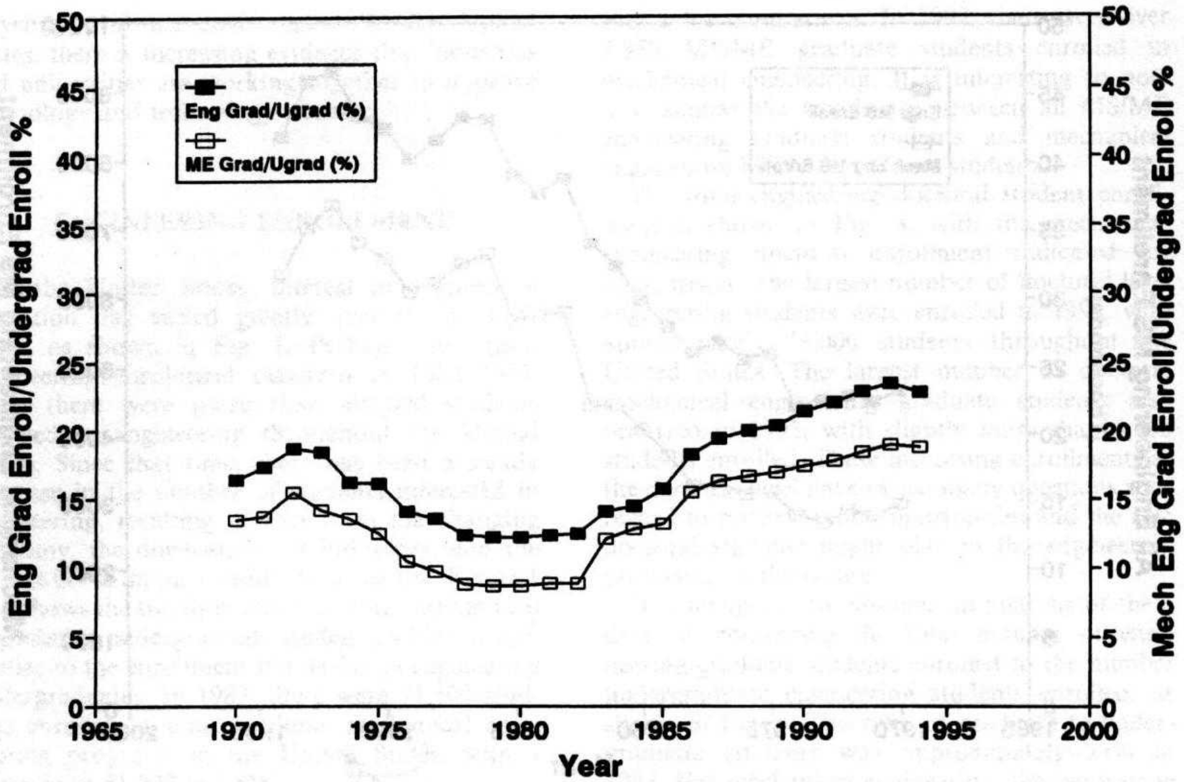

Fig. 4. A comparison of all graduate engineering undergraduate students enrolled with the percentage of mechanical engineering students for the past twenty-five years.

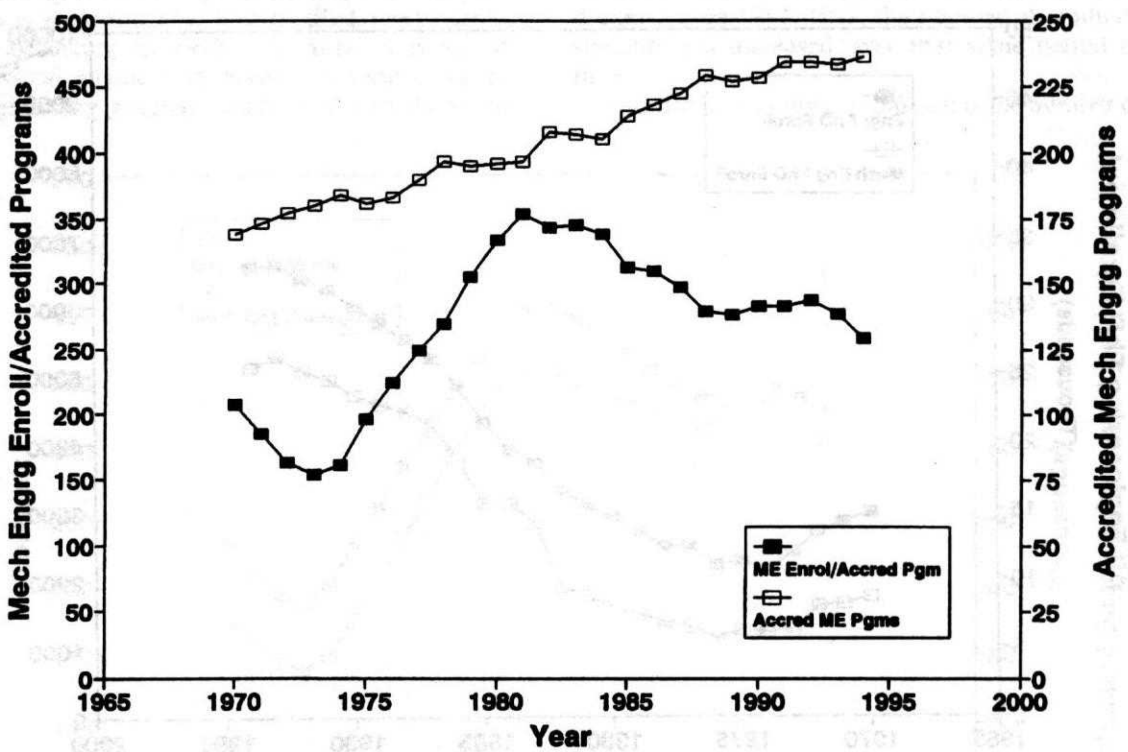

Fig. 5. A comparison between the number of accredited mechanical engineering curricula and the number of undergraduate mechanical engineering students enrolled in the curricula for the past twenty-five years.

students per degree program or per department. Today, the number of students enrolled in an average mechanical engineering program has declined to about 250 students per program.

There have been some dramatic oscillations in engineering and mechanical engineering enrollments over the past 25 years. Current trends suggest that there will continue to be some decreases in mechanical engineering enrollment over the next 10 to 20 years. Clearly, there is a need for a concentrated focus on modernizing mechanical engineering curricula and planning for the future of the profession.

MECHANICAL ENGINEERING ACCREDITATION CRITERIA

Essentially all engineering education programs must satisfy minimum levels of education through accreditation by the Accreditation Board for Engineering and Technology (ABET). Authorization for the accreditation of engineering degree programs in colleges and universities has been granted to ABET through the US Department of Education.

ABET is composed of representatives from all of the recognized engineering disciplines selected by their professional societies. These representatives are from academia, government, and industry, and reflect the views of these different sectors of engineering employment. It is this group of representatives, through the Engineering Accreditation Commission, that determines the accreditation criteria, recommends changes to the criteria, and conducts the accreditation process.

In the past, the general accreditation criteria used in the evaluation of engineering education programs was intended to assure an adequate foundation in science, the humanities and social sciences, engineering design methods, as well as preparation for an engineering specialization. The course work included at least one year of mathematics and basic sciences, one year of engineering science, one-half year of engineering design and one-half year of humanities and social sciences. In addition, the curriculum in mechanical engineering must provide an integrated educational experience, including laboratory experience, directed toward problem solving in both the thermal sciences and mechanical systems aspects of mechanical engineering. While the engineering content of the mechanical engineering program is important, it is also expected that students pursuing a degree in mechanical engineering would have appropriate computer-based experience as well as competency in written and oral communications, professionalism and ethics, and other related areas.

A mechanical engineering education program designated as an accredited program must satisfy the ABET general criteria and program-specific criteria. Representatives of ABET review and inspect undergraduate engineering programs, normally at six-year intervals, to ensure that the programs meet critical standards with respect to faculty, curricular objectives and content, student body, administration, institution facilities, and institutional commitment. Each year, a listing of accredited programs is published in the ABET Annual Report.

There has been significant interest in US engineering accreditation policies and procedures by institutions throughout the world. Many of these institutions have requested that a team, designated by the ABET International Activities Committee, visit their institution to evaluate their programs using ABET criteria. While ABET is not authorized to accredit programs outside the United States, it has defined a term 'substantially equivalent' to recognize those programs comparable to accredited programs in the United States. In this context 'substantially equivalent' means that an international program is comparable in content and educational experience to an accredited US program, and that the current state of the program is judged to meet or exceed the minimum general and program-specific ABET requirements for a program of that type. This implies reasonable confidence that the graduates of the program possess the competence needed to begin professional practice at the entry level. Over the past several years, ABET review teams have visited universities in such countries as Saudi Arabia, Mexico, Korea, Iceland, Turkey and Columbia. Many other programs are in various stages of preparation for such a visit.

MECHANICAL ENGINEERING CURRICULA

It is useful to trace the evolution of mechanical engineering by reviewing the early curricular requirements for a typical mechanical engineering program. The requirements for such a program are listed in Table 1 for a four-year baccalaureate program in mechanical engineering in the 1950s. Note the number of basic courses and the rather traditional third and fourth year required courses. There was also a limited choice of technical electives. While the curriculum appears rather traditional, it served the profession well, and many industrial leaders of today gained their education through such a curriculum.

With the rapid advancement of technology and the changing mechanical engineering field, mechanical engineering curricula also have changed. A typical mechanical engineering curricula for the 1990s is shown in Table 2. There have been significant changes in required courses, and the focus of the technical electives reflects advancing technology.

While not evident in these tables, the content and structure of the various required courses have also changed to take advantage of improved computer technology. Clearly, mechanical engineering education programs of today have improved as the technological world has developed. They have not, however, been modernized sufficiently to meet the needs of the next century.

In view of the rapid advances in technology, and the continual need to modernize mechanical engineering curricula, the American Society of Mechanical Engineers (ASME) has organized several Mechanical Engineering Department Head conferences to provide a forum for discussion of

Table 1 — Mechanical engineering: 1950s curriculum

First Year		Third Year	
Chemistry	Chemistry—Organic	Electrical Circuits	Fluid Mechanics
Engineering Drawing	Engineering Drawing	Mechanics of Materials	Kinematics
English Rhetoric	English Composition	Strength of Materials	Electrical Machinery
Algebra	Descriptive Geometry	Thermodynamics I	Thermodynamics II
Trigonometry	Analytical Geometry	Engineering Mechanics II	Machine Design
Engineering Problems	Engineering Problems	Elective	Business Law
			Elective
Second Year		**Fourth Year**	
Physics	Physics	Machine Design	Machine Design
Chemistry	Calculus	Power Engineering	Laboratory
English Literature	Machine Shop	Laboratory	Topical Seminar
American Government	Engineering Mechanics I	Internal Combustion Engines	Accounting
Calculus	Economics	Technical Writing	Public Speaking
Welding and Foundry	Surveying	Elective	Elective
Machine Shop			

Possible electives:	Mechanical Refrigeration	Physical Metallurgy
	Steam and Gas Turbines	Marine Engineering
	Automotive Engineering	Manufacturing Methods

Table 2 — Mechanical engineering: 1990s curriculum

First Year		Third Year	
Chemistry II	Engineering Analysis	Electrical Circuits	Manufacturing Systems
Chemistry Laboratory II	Engineering Math II	Structure of Alloys	Engineering Economics
Composition and Rhetoric	Physics—Mechanics	Mechanical Systems I	Fluid Mechanics
Engineering Graphics	Humanities	Applied Mathematics	Mechanical Design I
Engineering Math I	Humanities	Thermodynamics I	Thermodynamics II
Humanities			
Second Year		**Fourth Year**	
Humanities	Statistics	Mechanical Design II	Engineering Laboratory
Engineering Math III	Differential Equations	Heat Transfer	Seminar
Engineering Mechanics I	Technical Writing	Government	Mechanical Design III
Physics—Electricity/Optics	Engineering Mechanics	Humanities	Humanities
Materials Science	Humanities	Elective	Elective
			Elective

Possible electives:	Gas Dynamics	Acoustics
	Control Systems	Modern Materials
	Non-Destructive Evaluation	Turbo Machinery

mechanical engineering curricula [2, 3, 4]. The most recent conference focused on innovations in engineering design education for mechanical engineering students. Engineering design is one of the critical components of the industrial product realization process and relates directly to the improvement, quality, cost, and time-to-market for many products. Improving design methodology is the single most essential step to industrial excellence [5]. The conference discussion included the role of design projects in engineering education, design methodology and new paradigms for design, modem design tools, international dimension in design, interdisciplinary design, and integration of industry practice with design education.

The American Society of Mechanical Engineers is currently planning a new Mechanical Engineering Department Heads conference to address the globalization of mechanical engineering. Emphasis will be placed on engineering education curriculum and content, graduate education, lifelong learning, distance educational delivery systems, industrial experimental learning, codes, standards and registration, and other areas. These activities will provide mechanical engineering education leadership with the opportunity to maintain an awareness of changing technological needs, as well as trends in curriculum modification.

There have been no educational conferences directed specifically toward mechanical engineering curricula for the year 2020 or on the anticipated advances in educational delivery systems. The information available through computer networks suggest that significant changes will take place over the next 25 years. Students may learn through distance learning programs, alternate education systems, and home-study courses, as well as through traditional university programs. The mechanical engineering curricula for 2020 will probably include some basic rudiments of the present curricula, as well as other subjects, as shown in Table 3. Note that the proposed curriculum for the year 2020 will continue to be a four-year program, although many courses will differ from those of today. It is anticipated that secondary schools will provide more advanced education, permitting increased depth and breadth in the university level educational programs. International studies should be a component of both the academic and occupational educational programs. Technical electives also will be different, realizing that the mechanical engineer of the future must be prepared to work in a global environment.

CHANGING REQUIREMENTS OF INDUSTRY

With the advances in technology and the movement toward a global economy, it is important to consider industrial requirements for the future in terms of requirements for new employees, the balance of the work force, and the uncertainty in the interglobal economy. Employers, especially those with multinational operations, are concerned about the education and training of future employees [6, 7, 8]. Many corporations expect recent college graduates to have an understanding of international affairs, some knowledge of a second language, and a broad understanding of the role that cultural, political, economical, legal, and regulatory matters play in international operations. Cultural sensitivity is essential to effective performance in a global economy.

Recently, a small group of corporate leaders convened at a strategic round table to discuss the future industrial work force, as well as associated educational requirements. Through this discussion, a view of future employment requirements emerged.

In the field of engineering education, it is likely that most industries will incorporate lifelong

Table III—MECHANICAL ENGINEERING: 2020s CURRICULUM

First Year		Third Year	
Calculus	Calculus	Materials Science	Materials Processing
Chemistry	Biological Science	Gas Dynamics	Propulsion Systems
Physics	Physics	Mechatronics	Telecommunications
Humanities	Humanities	Human Factors/Biotechnology	Industrial Design
Computer Science	Engineering Analysis	Economics	International Relations
Numerical Methods	Materials Science	Laboratory	Laboratory
Second Year		**Fourth Year**	
Differential Equations	Statistics	Product Realization	Interdisciplinary Projects
Engineering Mechanics	Manufacturing Processes	Thermal Systems Design	Communications Design
Thermodynamics	Engineering Mechanics	Topical Seminar	Topical Seminar
Electronics	Computer Graphics/Simulation	Systems Engineering	Elective
Political Science	Transport Phenomena	Elective	Humanities
Elective	Philosophy	Humanities	

Possible electives: Environmental Engineering; Alternate Energy Systems; Global Industrial Processes; Organizational Systems; Noise Abatement Processes; Financial Management learning and distance learning as part of their employee requirements, with the virtual classroom becoming part of the educational process. Emphasis will be placed on maintaining and improving knowledge in new areas of technology appropriate to the industrial processes or products. There may be global outsourcing for lower-level engineering tasks with less emphasis on proprietary technologies. Industry will likely decrease its requirements for baccalaureate level engineering graduates, while placing greater emphasis on MS/ME level graduates with more maturity and experience. Emphasis will also be placed on industrial/academic partnerships to explore both basic research and applied research projects of mutual interest.

The workforce of the future will be older, more diverse, and broadly educated. More emphasis will be on basic technology competencies, bilingual and multicultural capabilities, as well as interdisciplinary team work skills. The industrial culture will be different, and mechanical engineering education programs must prepare students to work in these new environments.

In terms of industrial organizations, there will continue to be mergers, reductions in force, and restructuring. There will be a trend toward alliances, partnerships, and joint ventures with fewer and fewer industrial competitors. While competition helps maintain reasonable prices, it is not cost-effective in terms of duplication of effort. As a consequence, there will be more and more collaborative partnerships for large industrial projects and products. Virtual modeling and operational techniques also will be developed, as will communication networks and information management systems.

The global market will involve communications as one of the primary features. Global military, commercial, and political conditions will rapidly change, requiring a major re-analysis of many of the industrial products and systems we know today. The military market will shrink but space utilization and commercialization will grow. Research and development expenses may be shared increasingly in joint ventures with government.

Space systems will become a major market force in the future, with earth sensing devices, space medicine products, entertainment transmission, military and non-military surveillance systems, mobile satellite systems, energy generation systems, personal navigation systems, and environmental monitoring systems. There will be a revitalization of general aviation with low-cost, safe commuter aircraft an important product for the future. There may be efficient intermodal transport systems for long distance aviation, and advanced air traffic control systems will be aided by system integration.

Clearly, mechanical engineering education programs should be structured to prepare graduates for the future to compete in the international work force.

CONCLUSION

Numerous advances in technology will be made over the next 25 years. We have an opportunity and a challenge. We must focus our energy and resources on fostering an environment for creativity and innovation in our mechanical engineering education programs. We must look to the future, both individually and collectively. In mechanical engineering education, we must initiate more opportunities for creativity and challenge students to use their engineering skills to solve unusual and different problems.

Interaction between university faculty and students will lead to new ideas. It is possible to build a mechanical engineering education environment for creativity and innovation in the future. It is hoped that both the government and industries of the future will recognize the importance of mechanical engineering as a leader in technology development throughout the world, and its importance to the global market.

Mechanical engineering education programs provide an environment for intellectual growth and should respond to the challenges of the next century. All aspects of mechanical engineering education must be approached from a global perspective. Now is the time to plan for the future, to develop a mechanical engineering education program for the 21st century.

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